CHAPTER IX BOTTOM SEDIMENT COMPOSITION

A. INTRODUCTION

Lake sediments are important to limnologists because of their role in the determination of nutrient levels and productivity in the overlying waters.

A review of the factors that may affect sediment-water exchange reactions shows that there is insufficient knowledge at the present time to predict the extent and, in many cases, the net direction of exchange for many compounds in most natural waters. Lake sediments contain significant concentrations of many metals and nutrients. The lake sediments act as a buffer system for these elements to control concentrations in the overlying waters. The effect of this buffer system could be to keep the concentrations in the overlying waters relatively constant even though the concentrations of the element in the inflowing waters vary greatly (Lee, 1970).

One of the most important reactions of this type is the exchange of phosphorus between a lake's sediments and the overlying waters as related to the eutrophication of the waters. Lee (1970) states that lake sediments typically contain one to two parts per thousand of phosphorus per kilogram of dry sediment.

Knowledge is particularly lacking on the role of lake sediments in maintaining phosphorus levels in water. It is not known if the sediments of a lake act as a sink in which the majority of the phosphorus present is refractory, i.e., not available for exchange reactions, or as a source, contributing phosphorus to the lake to sustain plant growth.

Frink (1967) suggests that the center of a lake acts as a reservoir for both total and available nitrogen and phosphorus. He concludes that nutrients which accumulate in the bottom of a lake as eutrophication proceeds constitute a vast reservoir apparently capable of supporting plant growth in the event that nutrient input is reduced. This was the case at Kezar Lake, North Sutton, New Hampshire. Even after phosphorus loading was dramatically reduced from a point source, phytoplankton blooms continued on an annual basis. Phosphorus rich sediments continued to release phosphorus into the upper water column supporting a vast population of phytoplankton (Connor and Smith, 1983).

In addition to phosphorus, metal concentrations in the sediments can play a role in the ecological health of a lake. With the increasing concern of acidic precipitation in New Hampshire, lake or pond pH and Acid Neutralizing Capacity (ANC) have become increasingly important to the lake's health. Studies have shown various mechanisms of response of the lake's biota to increased acidity, ranging from the direct toxicity of the elevated hydrogen ion concentration to disruptions of normal food-chain relations and behavioral patterns of animals. Biogeochemical cycles in the lake may also be affected and, in turn, disrupt the biota. Recent studies have shown increasing concentrations of heavy metals such as manganese, aluminum and zinc as a result of pH depressions below five units.

B. CHEMICAL CHARACTERIZATION

A Wildco KB™ coring device was utilized to extract a 28.0 cm sediment core from the South Station of Great Pond and a 23.0 cm core from the North Station. The cores were sectioned off into one centimeter sediment column intervals. Metals were digested using a CEM Model 81 microwave digestion unit and run on an inductively coupled plasma atomic emission spectrometer (ICP). Sediment phosphorus concentrations were determined colorimetrically after digestion. Such measurements provide information on deposition rates, toxic metal concentrations, phosphorus sediment accumulation, and spatial variability over time.

When assessing spatial variability of elements throughout the core over time, one must use caution. Iskandar and Keeney (1974) stated that the concentration distribution of any element in a sediment profile must be treated cautiously due to mixing of the sediments. This was reiterated by Lee (1970) who stated that at least partial mixing of the sediments occurs for 5-20 cm below the sediment surface. This mixing occurs due to both natural processes and man-induced conditions. Natural mixing processes include thermal gradients, wind pressure and waves, organism mobility (i.e. insect larvae and worms) and the formation of gas bubbles and pockets. Man-made mixing occurs due to recreational activities (i.e. boating) or artificial mixing of the lake. In addition to mixing, some elements can diffuse upward due to differing gradients in the overlying water. For this reason the general trends in concentrations are more relevant than the segment to segment variances.

Comparison of other lake sediment core analyses performed in New Hampshire are presented in Table IX-1. Summary tables of sediment analyses from Great Pond appear in Table IX-2 and IX-3.

C. SEDIMENTATION RATES AND SEDIMENT AGE

The relative age of the sediments of New Hampshire ponds are estimated using lead concentrations as an indicator. A typical sediment profile shows lead concentrations increasing with depth to a maximum at several inches below the surface, and subsequently decreasing again. This peak corresponds to the introduction and increased use of leaded gasoline during the 1920's and its later decline during the seventies with the introduction of unleaded gasoline. Values from lakes that do not have point source discharges usually display these trends.

The Connecticut Department of Environmental Protection estimated that 2.0 feet (0.61 meter) of sediment had been deposited in eutrophic Lake Lillionah between 1955 and 1980. This equals a sediment deposition rate of approximately 1 in. (2.5 cm) yr^{-1}. Sedimentation in Lake Lillionah is unusually high, as compared to most Connecticut lakes, in that Lillionah experiences dense summer blooms of blue-green algae and receives indirect discharge of treated wastewater from an upstream sewage treatment plant. Peterson et al., (1973) discusses sedimentation rates for Lake Trummen, located in Sweden. Approximately 40 cm of FeS-colored (black) fine sediment was deposited over a period of 25 years, or at a rate of about 0.6 in. (1.6 cm) yr^{-1}. Lake Trummen was also subjected to the discharge of wastewater effluent for many years, and the significance of internal nutrient recycling was well documented. At mesotrophic Stockbridge Bowl, located in Stockbridge, Massachusetts, Ludlam (1976) reported a much lower sedimentation rate of 0.12 inches (3.0-3.2 mm) $year^{-1}$. The Maine Department of Environmental Protection assumes an approximate sedimentation rate of 0.08 inches (2.0 mm) $year^{-1}$.

The North and South Stations depict a typical New Hampshire lead deposition profile. Sediment lead increases dramatically at eleven centimeters and again at nine centimeters. Lead shows its maximum peak (North Station) at four centimeters which is fairly recent. Lead decreases

Table IX-1

Comparison of Surface Sediments (first inch) of Great Pond and New Hampshire Lakes and Ponds

Classification	Al	Cd	Cu	Fe	Pb	Zn	P
Eutrophic	11,945	7	< 20	> 15,000	134	131	2,091
Eutrophic	12,029	14	24	71,548	259	245	2,239
Mestotrophic	14,472	4	24	17,523	199	142	1,759
Mestotrophic	19,278	4	19	18,228	154	127	1,315
Eutrophic	7,660	4	20	7,840	155	105	982
Eutrophic	7,547	5	26	19,136	494	179	1,484
Eutrophic	23,760	5	26	26,460	139	227	2,359
Oligotrophic	16,800	< 4	< 80	13,120	101	80	7,128
Mesotrophic	20,500	1	17	26,000	94	140	4,735
Oligotrophic	25,120	< 24	<80	16,320	98	184	4,530
Mesotrophic	14,921	< 24	< 80	30,595	48	159	7,211
Eutrophic	23,585	< 236	830	16,038	58	6,604	5,569
Eutrophic	16,812	< 30	69	27,525	732	317	10,165

All values in mg/kg Dry Weight of Sediment

*Method Utilizing CEM Microwave (except Mn and Tp)

Table IX-2

Recoverable Metals From Great Pond (North) Sediments (mg/kg)

Sediment Section (cm)	Dry Weight (grams)	Al	Cd	Ca	Cu	Cr	Fe	Pb	Mg	P	K	Na	Zn
0-1	1.001	12,018	7	4,279	19	38	> 18,541	133	1,501	1,989	675	530	121
1-2	1.001	11,868	7	4,066	19	40	> 18,531	137	1,480	2,030	735	482	121
2-3	1.002	11,936	8	3,810	22	42	> 18,523	177	1,518	2,409	805	464	167
3-4	1.000	12,740	9	3,809	26	44	> 18,570	287	1,636	2,149	691	421	197
4-5	1.003	13,838	9	4,050	27	46	> 18,514	396	1,729	2,096	839	439	229
5-6	1.000	13,610	9	4,076	26	44	> 18,580	277	1,658	2,002	755	388	212
6-7	1.001	13,496	8	4,094	25	42	> 18,571	248	1,630	2,129	729	364	201
7-8	1.003	13,589	8	4,321	26	41	> 18,534	215	1,632	1,904	775	360	289
8-9	1.001	13,267	8	4,264	23	40	> 18,571	204	1,598	1,997	679	339	208
9-10	1.000	13,330	8	4,319	22	40	> 18,600	201	1,615	1,984	692	325	172
10-11	1.001	12,747	8	4,289	21	39	> 18,581	118	1,563	1,923	618	317	154
11-12	1.000	12,580	7	4,255	21	39	> 18,600	176	1,539	2,219	629	321	142
12-13	1.002	11,886	6	4,192	17	36	> 18,573	125	1,428	1,895	544	279	111
13-14	1.000	11,580	6	4,146	15	35	> 18,620	103	1,399	1,844	521	265	95
14-15	1.001	11,219	6	4,116	13	33	> 18,601	71	1,335	1,820	528	244	75
15-16	1.002	11,237	6	4,078	13	33	> 18,583	59	1,330	1,765	562	252	71
16-17	1.001	10,819	6	4,031	12	33	> 18,611	46	1,290	1,607	522	248	66

17-18	1.000	9,450	5	4,290	11	29	> 18,630	31	1,123	1,572	440	205	56
18-19	1.000	9,400	5	3,564	10	29	> 18,640	32	1,078	1,495	431	205	54
19-20	1.001	9,291	5	3,495	12	28	> 18,621	29	1,019	1,489	428	217	52

Table IX-3

Recoverable Metals From Great Pond (South) Sediments (mg/kg)

Sediment Section (cm)	Dry Weight (grams)	Al	Cd	Ca	Cu	Cr	Fe	Pb	Mg	P	K	Na	Zn
0-1	1.001	11,618	14	4,388	24	56	72,427	241	1,463	2,378	844	713	240
1-2	1.000	12,250	14	4,088	25	58	70,400	260	1,481	1,998	871	540	249
2-3	1.000	12,410	14	4,230	24	56	72,000	291	1,507	2,443	849	590	244
3-4	1.001	12,817	13	4,095	25	51	64,236	307	1,529	2,317	852	508	242
4-5	1.004	12,868	13	4,137	26	51	64,741	310	1,539	2,327	842	492	270
5-6	1.001	13,047	13	4,118	27	50	60,739	322	1,536	2,239	802	434	265
6-7	1.003	13,958	14	4,172	28	53	59,322	354	1,654	2,203	903	428	280
7-8	1.001	14,166	12	4,205	27	51	58,441	352	1,680	2,170	942	403	275
8-9	1.002	14,201	11	4,932	26	49	56,088	316	1,605	2,308	892	381	259
9-10	1.001	14,156	10	4,159	26	46	52,747	291	1,591	2,110	896	365	260
10-11	1.003	13,131	9	4,202	20	41	45,424	181	1,529	1,945	725	315	212

11-12	1.003	12,762	8	4,398	16	40	41,166	121	1,454	1,940	722	306	161
12-13	1.002	12,635	8	4,473	16	40	42,126	106	1,480	2,099	678	282	153
13-14	1.002	12,385	7	4,497	15	38	39,491	93	1,515	2,108	667	288	149
14-15	1.005	12,448	8	4,532	15	39	39,134	86	1,473	2,051	662	259	145
15-16	1.001	11,259	6	4,297	12	34	33,916	41	1,300	1,707	597	261	107
16-17	1.005	10,756	7	4,759	11	34	35,283	32	1,221	2,613	521	249	97
17-18	1.002	11,078	6	4,499	11	34	33,283	23	1,237	2,006	597	254	97
18-19	1.002	11,068	6	4,492	10	33	33,174	19	1,227	2,011	612	252	91
19-20	1.001	10,729	7	4325	14	37	18,601	63	1,218	2,188	537	241	132
20-21	1.002	12,225	8	4297	18	42	18,583	112	1,427	2,203	623	265	158
21-22	1.000	10,770	7	4366	12	36	18,630	389	1,250	2,061	524	217	80

in the upper three centimeters which reflects a reduction in atmospheric lead deposition as a result of the increased use of unleaded gas.

D. SEDIMENT METALS AND PHOSPHORUS

Values presented in the following discussion are for concentrations which were measured in the sediment, not in the water. Elevated metal concentrations would not be expected to be measured in lake water unless low pH values (below 5.0 units) were commonly measured within the lake.

1. Recoverable Aluminum

One of the most abundant elements on the face of the earth, aluminum occurs in many rocks but never as pure metal in nature. Although the metal itself is insoluble, many of its salts are readily soluble.

The toxicity of aluminum to the aquatic biota has been reviewed extensively with the recent interest in the resolublization of aluminum in acidic waters. Aluminum toxicity does not appear to be a significant problem, as long as pH is controlled and residual dissolved aluminum is not allowed to reach levels in the area of 50 μg/L. In areas where lakes have low ANC and acid rainfall is significant, lowering the lake pH could cause a sudden increase in aluminum and probable toxic effects to the lake biota.

Aluminum concentrations from the North and South Stations at Great Pond can be found in Tables IX-2 and IX-3. Aluminum values from the North Station of Great Pond ranged from a minimum of 9,291 mg/kg (19-20 cm segment) to a maximum of 13,838 mg/kg (4-5 cm segment), while the South Station had values ranging from 10,729 mg/kg (19-20 cm segment) to 14,201 mg/kg (8-9 cm segment). Aluminum concentrations in the sediments in both stations remained relatively stable throughout the profile, and the North and South profiles are fairly similar when compared to one another (Figure IX-1).

The aluminum values for the first inch of sediment cores from the North and South Stations at Great Pond were lower than those found at most other lakes and ponds in New Hampshire (Table IX-1).

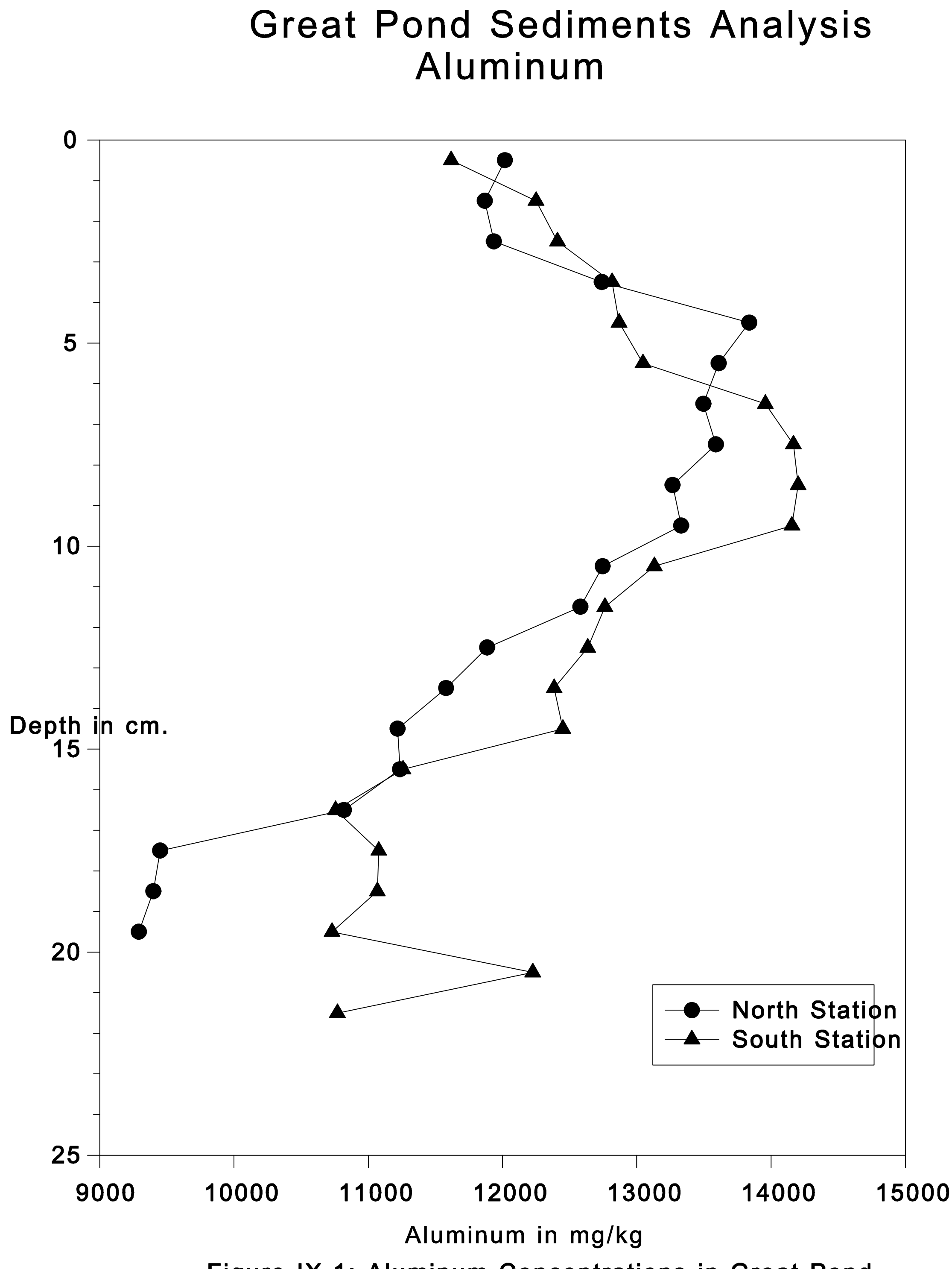

Figure IX-1: Aluminum Concentrations in Great Pond Sediment

2. Recoverable Cadmium

In the elemental form, cadmium is insoluble in water. It occurs in nature largely as a sulfide salt. Cadmium is used in metallurgy to alloy with copper, lead, silver, aluminum and nickel. It is also used in electroplating, ceramics, photography, batteries and insecticides.

Cadmium levels analyzed from the sediment cores at both lake stations in Great Pond were below 15 mg/kg throughout the sediment profiles and remained relatively stable. As Figure IX-2 illustrates, the North Station sediment profiles displayed a minimal increase in cadmium from the 19-20 cm segment to the top of the profile, while the South Station displayed a modest increase from the bottom to the top of the profile. Maximum cadmium values were observed in the upper portion (5 cm or less) of each lake station. Cadmium levels in the sediment of the North Station ranged from 5 mg/kg (19-20 cm segment) to 9 mg/kg (0-1 cm segment) and was slightly higher than data collected from other New Hampshire lakes and ponds (Table IX-1). A similar, but slightly higher range in cadmium levels was observed in the South Station sediments with values ranging from 6 mg/kg (18-19 segment) to 14 mg/kg (0-1 cm segment). Cadmium data for the North and South Stations is presented in Tables IX-2 and IX-3 respectively.

3. Recoverable Copper

Copper salts occur in natural surface waters only in trace amounts, up to about 50 ug/L, and their presence is frequently due to the use of copper sulfate for the control of nuisance plankton species. Copper is used in many alloys, insecticides, fungicides, and wood preservatives. Copper values from the North and South Stations of Great Pond ranged from 10 mg/kg to 27 mg/kg and from 10 mg/kg to 28 mg/kg respectively (Tables IX-2 and IX-3). Copper values increased from the bottom to the top of the sediment profile at both lake stations (Figure IX-3), and both profiles were fairly similar when compared to one another. In comparison with other New Hampshire lakes and ponds, surface sediments in both the North and South Stations at Great Pond contained levels of copper that fell within the observable mean (Table IX-1).

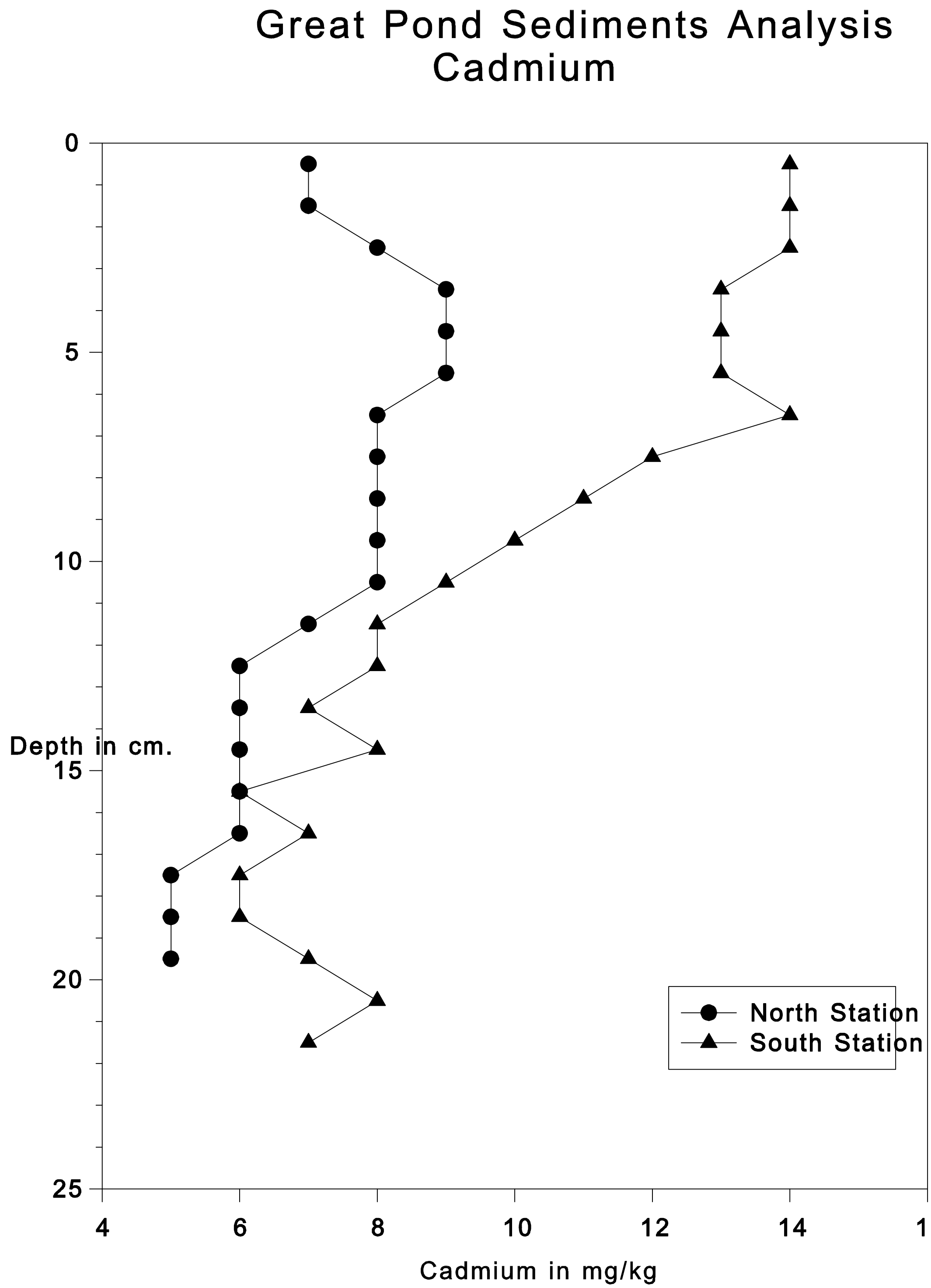

Figure IX-2: Cadmium Concentrations in Great Pond Sediment

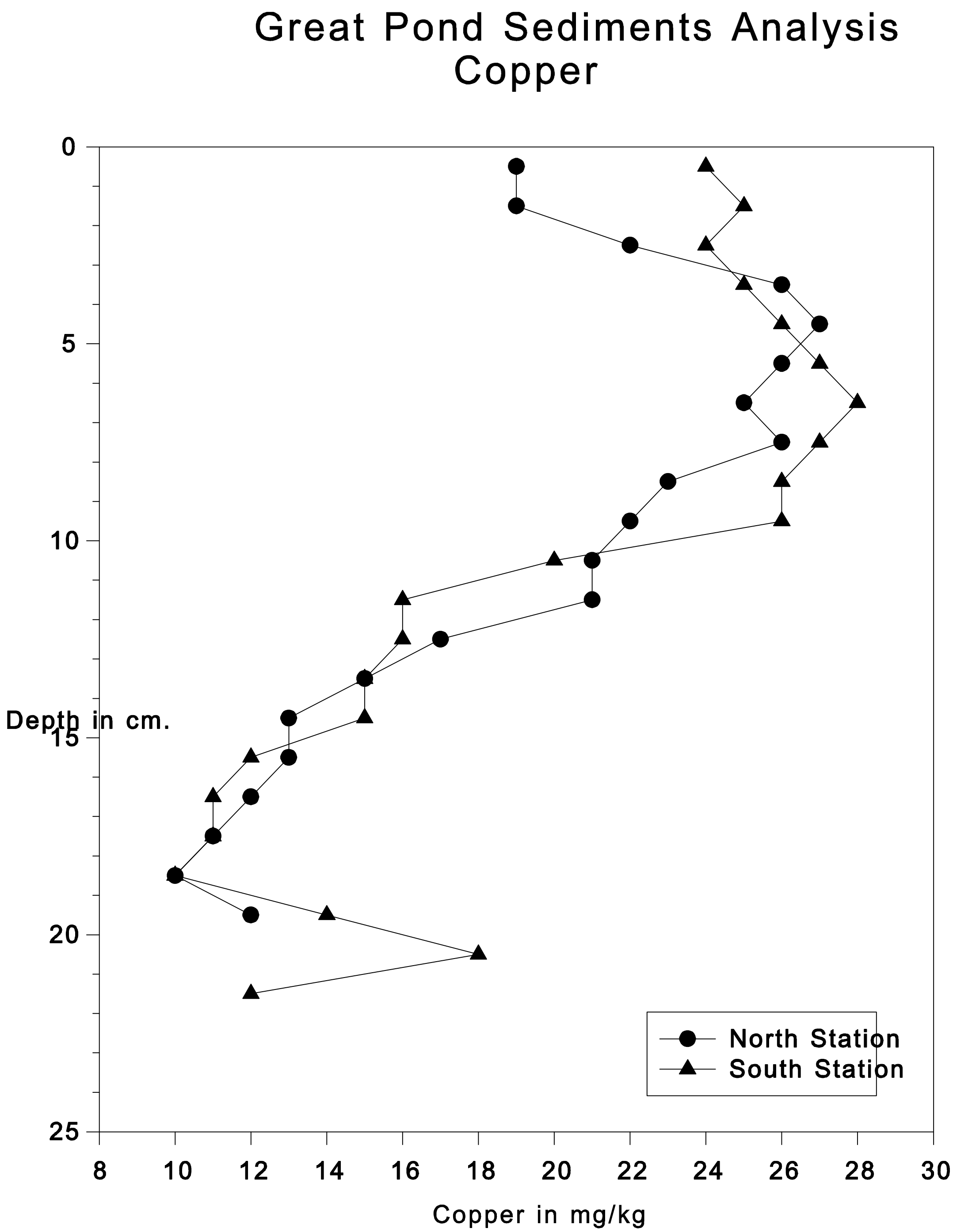

Figure IX-3: Copper Concentrations in Great Pond Sediment

4. Recoverable Iron

Iron is the fourth most abundant by weight of the elements that make up the earth's crust. Common in many rocks, it is an important component of many soils, especially the clay soils. The two Great Pond sediment samples were run at two different times. At the time the North Station was analyzed by the NHDES chemistry lab, the ICP instrument was apparently calibrated for a lower range. The results for the North Station all came out above the calibration curve, and are excluded from discussion here. Iron values for Great Pond sediments are displayed in Tables IX-2 and IX-3, and Figure IX-4. The Great Pond South Station had a highly variable range of iron, from 18,583 to 72,427 mg/kg. The South Station had minimum iron values in the deepest sediments with concentrations increasing to the maximum at the surface sediments. The Great Pond South Station contained high levels of iron in surface sediments when compared to other lakes and ponds sampled in New Hampshire (Table IX-1).

5. Recoverable Lead

Leaded gasoline introduced in the 1920's has been largely blamed for the increased levels of lead observed in the aquatic environment, while the introduction of unleaded gasoline in the early 1970's was responsible for a reduction in atmospheric deposition. The solubility of lead compounds in water depends heavily upon pH. Fish kept in water of pH 6.0 concentrate almost three times more lead than fish kept in water of pH 7.5. This is of startling significance for the northeast where lake waters are generally poorly buffered and acid precipitation is further decreasing the pH in many of our lakes and ponds.

Recoverable sediment lead concentrations ranged from a low of 19 mg/kg in the South Station to a maximum of 396 mg/kg in North Station sediments. The North and South Stations at Great Pond displayed a wide variance in lead content with depth. Except for a strange spike seen at the bottom of the South Station, the deepest segments had minimal values and the general trend showed a gradual increase until the 6-7 cm segment in the South Station and the 4-5 cm segment in the North Station, at which point the concentration rose sharply (Tables IX-2 and IX-3, Figure IX-5). A comparison of the surface sediment lead concentration of Great Pond with other lakes and ponds in New Hampshire shows greater than average levels in the North and South Stations (Table IX-1).

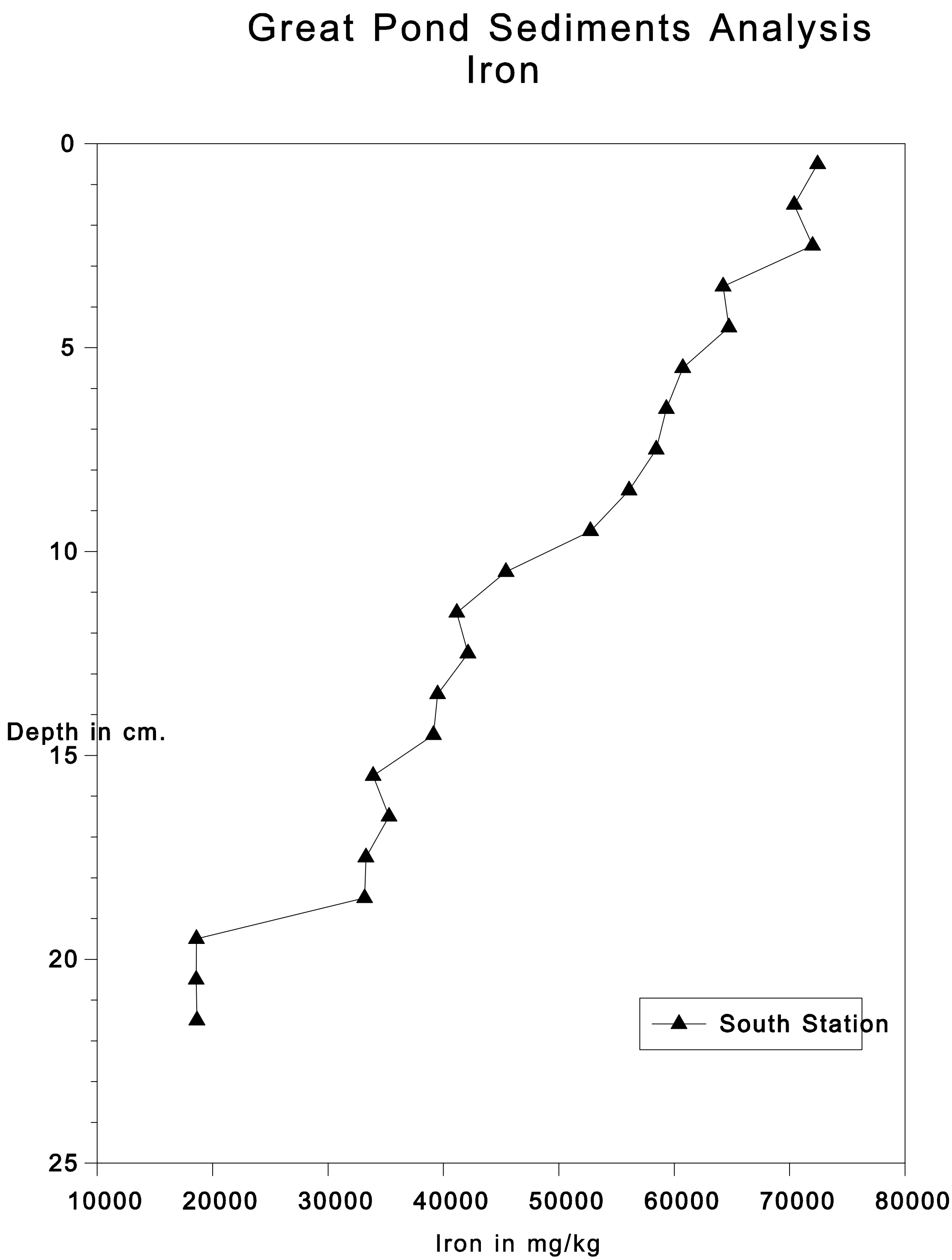

Figure IX-4: Iron Concentrations in Great Pond Sediment

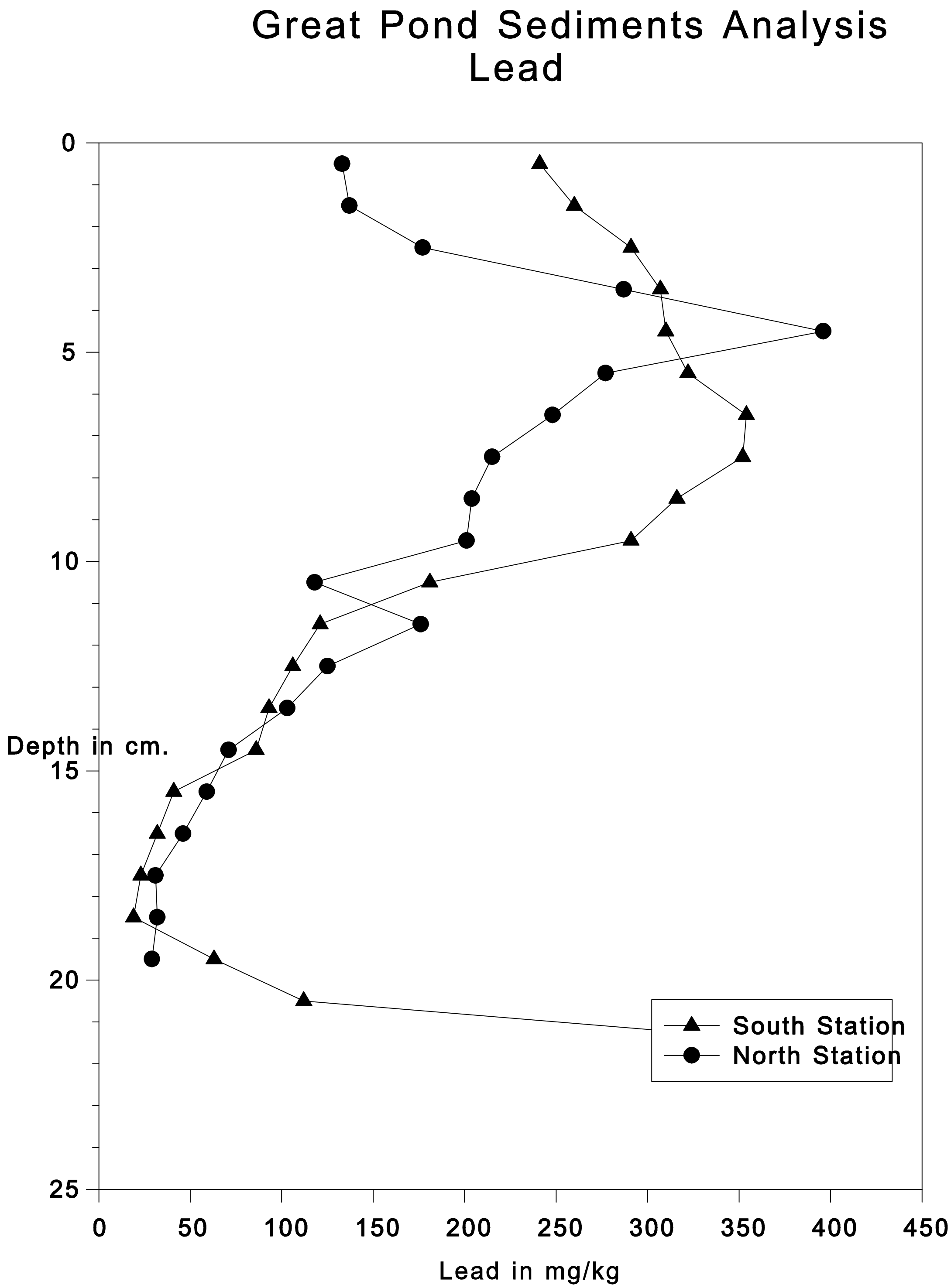

Figure IX-5: Lead Concentrations in Great Pond Sediment

6. Recoverable Zinc

Compounds of zinc are soluble in neutral and acidic solutions, so that zinc is readily transported in most natural waters and is one of the most mobile of the heavy metals. Zinc is used for the anti-corrosive coating in galvanized metals and rubber products.

Most of the zinc introduced into the aquatic environment is partitioned into the sediments by sorption onto hydrous iron and manganese oxides, clay minerals, and organic materials. All zinc forms are potentially toxic if they can be sorbed or bound by biological tissue.

Sediment zinc concentrations ranged from 80 mg/kg to 280 mg/kg in the South Station and from 52 mg/kg to 289 mg/kg in the North Station of Great Pond (Tables IX-2 and IX-3). As with most other chemicals analyzed, zinc levels for both lake stations had a general increase in concentration from the deepest segments to the surface of the sediment profiles (Figure IX-6), but with a maxima 5 to 8 cm. below the surface. Comparison of values with the surface sediments of other New Hampshire lakes and ponds reveals that Great Pond had average concentrations of zinc in the uppermost layers of the sediment profiles collected at both lake stations (Table IX-1).

7. Recoverable Phosphorus

The measurement of phosphorus concentration in a lake gives an indication of the extent of nutrient enrichment. The amount of phosphorus in New Hampshire lakes determines the level of plankton growth. Lake sediments often act as sinks and accumulate high concentrations of phosphorus over long periods of time. Phosphorus which has accumulated in the deep water sediments of a lake may be released into the water when the physical, biological and chemical conditions become conducive for its release. Usually, this release occurs during the summer months. If stratification is weak, this phosphorus migrates to the metalimnion to be utilized by the plankton community; otherwise, much of this hypolimnetic phosphorus is distributed to the entire water column during the fall overturn.

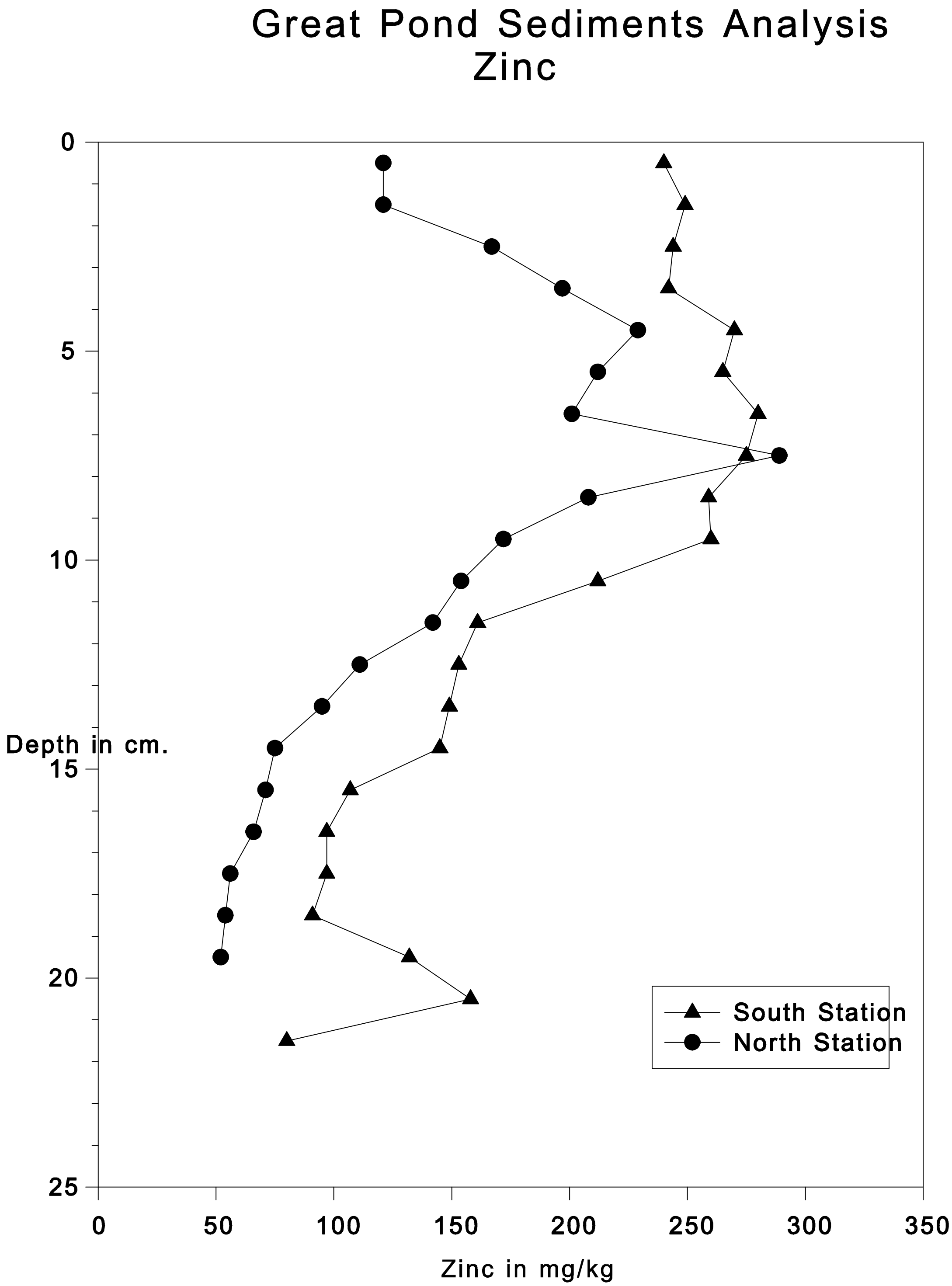

Figure IX-6: Zinc Concentrations in Great Pond Sediment

The identification of sediment phosphorus concentration is important to the phosphorus budget. Spatial distribution of sediment phosphorus with depth is important in the evaluation of lake restoration techniques and their feasibility. For example, the uniform distribution of high concentrations of phosphorus throughout the sediment column would obviously make dredging an unfeasible restorative technique. However, sediment sealing with aluminum as a restorative technique might be a solution for this type of problem.

Most studies show that lake sediments typically contain 1000-2000 mg/kg of recoverable phosphorus. In twenty-seven borderline mesotrophic/eutrophic lakes located in Massachusetts, the mean concentration was 1,268 mg/kg, while concentrations of recoverable sediment phosphorus in fifteen New Hampshire lakes ranged from 100 to almost 14,000 mg/kg. Sediment phosphorus concentrations in Lake Washington, Washington State, (Edmondson, 1972) ranged from 1000 to 6000 mg/kg while the range in Lake Shagawa, Minnesota, was 1000 to 5000 mg/kg (Larson et al.,1975).

The minimum value of sediment phosphorus in the core collected from the North Station at Great Pond was 1,489 mg/kg (19-20 cm segment), while the maximum was 2,409 mg/kg in the 2-3 cm segment. The range of phosphorus values in the South Station core was similar but slightly higher, with a minimum value of 1,707 mg/kg (15-16 cm segment) and a maximum of 2,443 mg/kg in the 2-3 cm segment (Table IX-3). The trend of the sediment phosphorus concentration profile from both stations is similar to its metal profiles, with minimal values in the deepest segment and increasing to the surface layer. The higher phosphorus values observed in the South Station reflect the differences in morphometry and bottom substrate composition at each lake station.

The surface sediments from both Great Pond sample stations were similar to the mean phosphorus concentrations of other New Hampshire lakes and were well within the range (range=982-10,165) of other sediment phosphorus concentrations analyzed in New Hampshire (Table IX-1).

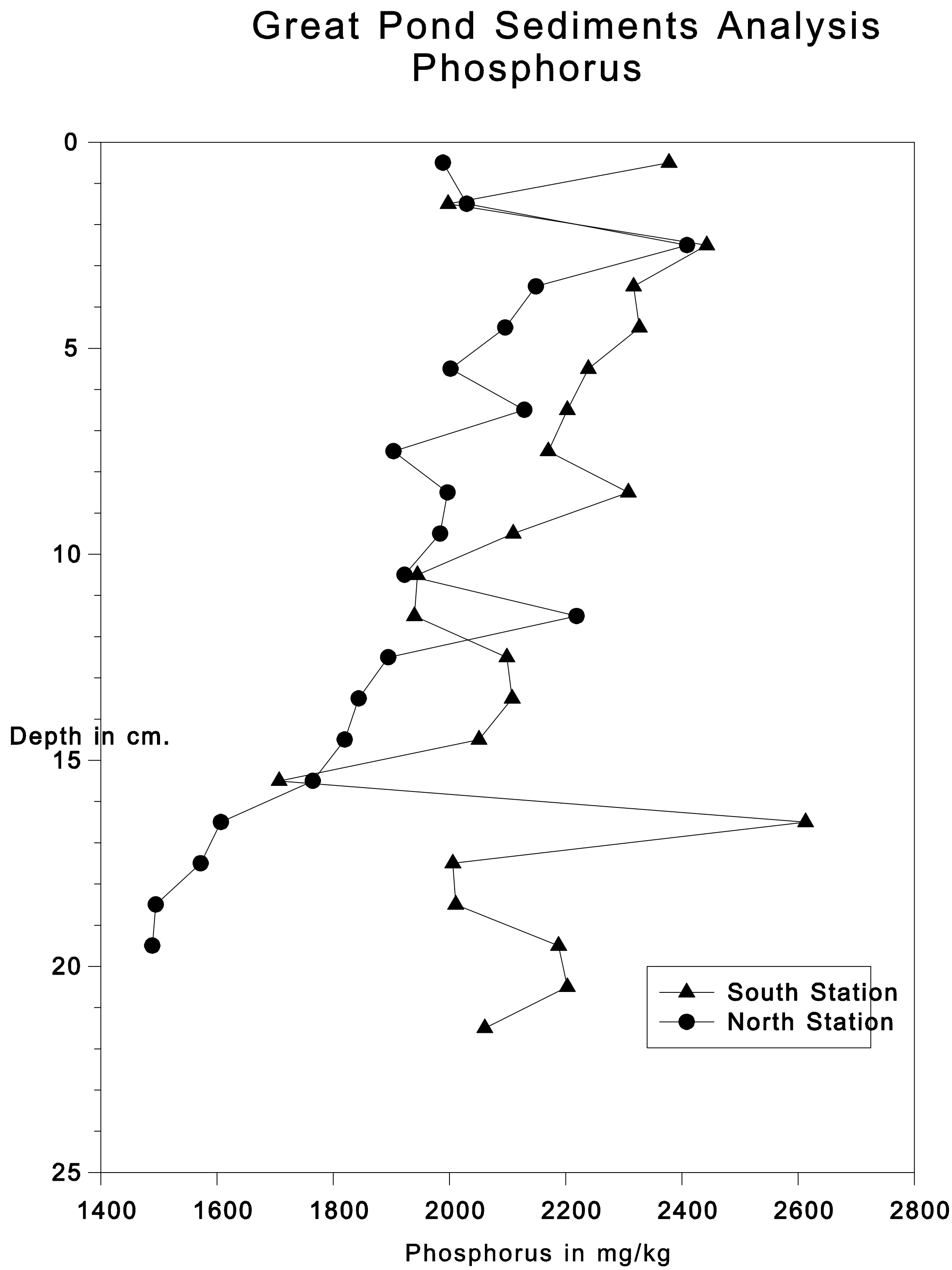

Figure IX-7: Phosphorus Concentrations in Great Pond Sediment